COMPUTER SIMULATION OF HIGH PRESSURE SLUDGE LIQUEFACTION REACTOR

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Keywords: mathematical model, sewage/waste water sludge, high pressure liquefaction

INTRODUCTION

The increasing population of municipal area and the improved activity of the economy are causing more polluted water in streams. However, the public demand more action on the environmental protection, resulting in more than 70% treatment of total sewage/waste water in 1997. The volume of sludge from the sewage/waste water treatment plants is increasing and it is expected to be 8000 ton per day in 1997. Seventy to eighty percent of water content in the sludge makes landfill of sludge an ineffective way of treating sludge. Thus, the development of sludge treatment technologies is inevitable in the direction of reducing water content of sludge to prevent odor generation and to reduce the leaching of heavy metal in some area.

Overall objective of this research is to develop a sludge treatment technology to recover organic portion of sludge as a fuel oil using a high pressure liquefaction technique. The result would be the reduction of the volume and the weight of sludge to be land filled while generating useful energy from wastes. A bench scale liquefaction process has been operated for several months and the scale up process is underway.

The detailed understanding of the behavior of a high pressure sludge reactor during transient operation is crucial to the design of scale up process.

THEORETICAL FOUNDATION OF THE MODEL

Nature of the Analysis

The starting point of the present analysis is the set of elliptic partial-differential equations that express the conservation of mass, momentum and energy in two-dimensional transient non-Newtonian flow.

These equations are reduced to finite-difference equations exhibiting 'upwind' formulation of the coefficients over a grid that covers the domain of interest. Appropriate boundary conditions are supplied to the procedure which is incorporated into a computer program. The computation is a set of grid-node values for the velocity components, pressure, and temperature.

Differential Equations

All dependent variables such as velocity components in two dimensions and energy, with the exception of pressure, appear as the subjects of differential 'conservation' equations. Although these equations are deduced from physical principles, they are all expressed in a standard form, in which Φ stands for a generic fluid property [1,2].

$$div\{(\rho \upsilon \Phi + J_\Phi)\} = S_\Phi \quad (1)$$

where ρ, υ, J_Φ,S_Φ are density, velocity vector, diffusive-flux vector and source rate per unit volume.

The pressure variable is associated with the continuity equation:

$$div(\rho \upsilon) = 0 \quad (2)$$

in anticipation of the so-called pressure correction equation [1] which is deduced from the finite-difference form of the continuity equation.

The diffusive flux J_Φ is given by:

$$J_\Phi = -\Gamma_\Phi grad\Phi \quad (3)$$

where Γ_Φ denotes the effective exchange coefficient of Φ.

DETAILS OF COMPUTATIONS PERFORMED

Outline

Because of the exploratory nature of the computations, simplifications in the modeling of the reactor have been introduced. These simplifications include the treatment of the problem as two-dimensional, axi-symmetric reactor. A coarse-grid, consisting of 84 x 18 control cells, has been chosen, and grid-spacing is such as to model the geometric features as accurately as

possible shown in Fig. 1.

Initial and Boundary Conditions

To complete the mathematical analysis, it is necessary to provide initial and boundary conditions. For the typical reactor problem illustrated in Fig. 2, these conditions are as follows:

- At the inlet to the reactor, mass flux of sludge and temperature are prescribed; the momentum flux at the inlet is computed from the prescribed mass flux and the known area. Temperature is defined with respect to incoming sludge and is therefore set equal to room temperature. Table 1 shows the inlet velocities based on the various speed of pump strokes.
- At the reactor wall, the non-slip condition is used for velocity components parallel to the wall. Thermal boundary conditions on reactor wall can be modeled with specified temperatures due to three zone heaters around the wall.

Physical Properties

Physical properties of sludge (thermal conductivity, heat capacity, density) assumed same as those of water since sludge contains 80 - 90% of water. Unreacted raw sludge behaves as a highly non-Newtonian flow. However, when heated in the reactor vessel, it quickly turns Newtonian flow. Viscosity of the sludge is assumed to be a function of temperature.

The Solution Procedure

The procedure adopted for the solution of the equations is the SIMPLE algorithm[1]. The reader is directed to the above reference for further details.

PRESENTATION OF THE RESULTS

Many results were obtained during the present study but space considerations dictate that only a part of these can be presented. Representative sample predictions for two cases are shown in Figs. 3 and 4, mainly in the form of maps of temperature distributions. Fig. 5 is the streamline contours.

DISCUSSION OF RESULS

The coarseness of the finite-difference grid used does not allow the results to be quantified in detail. It does allow, however, the description of their qualitative nature, and the study of the relative differences coming from changes to design conditions.

Table 2 shows experimental conditions such as reaction time and a temperature at each zone for runs performed.

The temperature distribution across the reactor is presented in Figs. 3 and 4 at 5, 15, and 30 minutes for Cases 1 and 8. It can be seen that first section of the reactor could serve as a preheating zone. Since the temperature development through the reactor is strongly affected by the second and third heaters as well as the sludge residence time, these variables should be optimized to minimize coking phenomena on the reactor wall. Fig. 5 is the streamlines which represent the flow field of the fluid in the reactor. Due to the highly viscous of initial sludge condition the inlet velocity to the reactor is quite slow, eddies caused by sudden expansion do not appear. This allows the simple design of reactor is feasible. The predicted average outlet temperature and the outlet temperature experimentally obtained are shown in Table 2. Predicted outlet temperatures was 15 - 20 % higher than experimental outlet temperature. This is due to the sludge cokes formed on inner reactor wall which inhibits a heat transfer from the wall.

CONCLUSIONS

A numerical modeling approach is developed for prediction of transport phenomena in the high pressure sludge reactor using the operation parameters of the laboratory scaled continuous process. The heat transfer phenomena in the reactor was reasonably predicted and will be better predicted including the sludge coking effect. The computer modeling tools are based on a computational fluid dynamics code developed in our laboratory.

Although the test cases considered in this paper are rather limited, the computer program can handle more complicated situations and serve as a useful design guide.

REFERENCES

[1] Spalding, D.B., Recent Advances in Numerical Methods of Fluids, 1 (1980).
[2] Yasuda, Y., Water Science and Technology, 23 (1991)

Table 1. Pump stroke and inlet velocity

Retention time (min)	pump stroke	volumetric flow rate (ml/hr)	inlet velocity (m/s)
16	50	1871	0.01242
20	40	1406	0.00933
30	30	1070	0.00710

Table 2. Experimental conditions for runs performed

Case No.	Retention time	heating zone 1 (°C)	heating zone 1 (°C)	heating zone 1 (°C)	outlet temp (°C)
	SET	130	250	250	
1	16	121	251	241	109
2	16	121	209	247	103
3	16	125	216	242	109
4	20	125	222	245	112
5	20	125	200	245	116
6	30	134	241	233	120
7	30	134	234	222	113
	SET	130	300	300	
8	16	115	265	304	131
9	16	119	262	304	131
10	16	131	264	295	133
11	20	133	258	262	129
12	20	132	257	263	129
13	30	140	257	300	128
14	30	140	258	298	127
15	30	141	257	299	127

Table 3. Comparison between experimental and numerical results.

	Experimental outlet temperature	Predicted outlet temperature
Case 1.	382 K deg	446.13 K deg
Case 8.	404 K deg	482.63 K deg

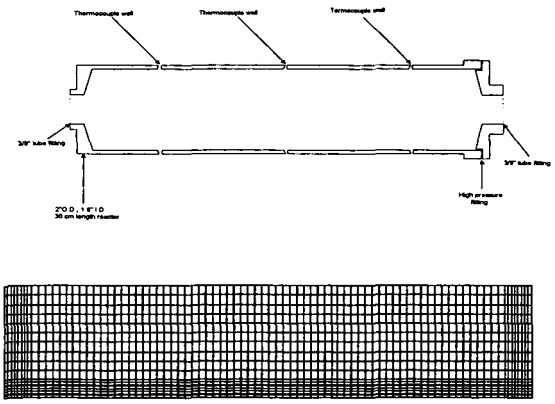


Figure 1. The sludge reactor considered and its finite difference representation

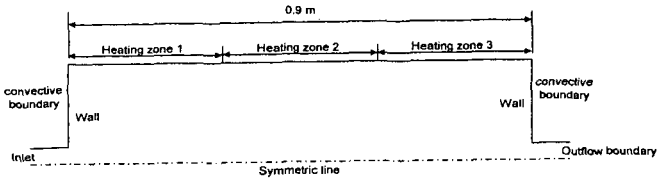
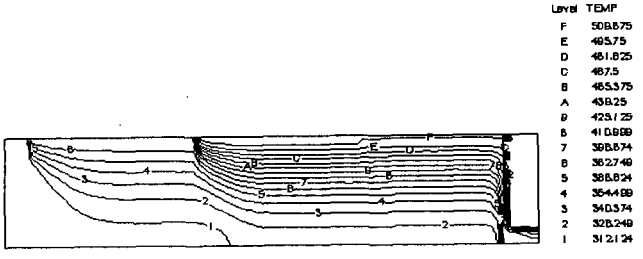
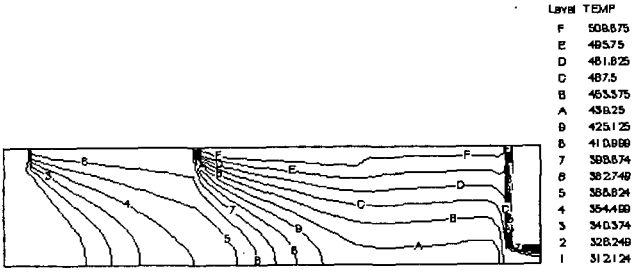


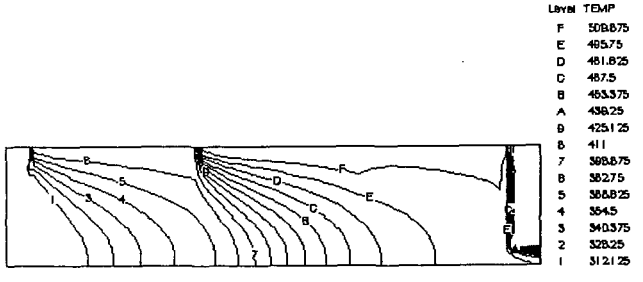
Figure 2. Schematic of sludge reactor



(a) Time = 5 min

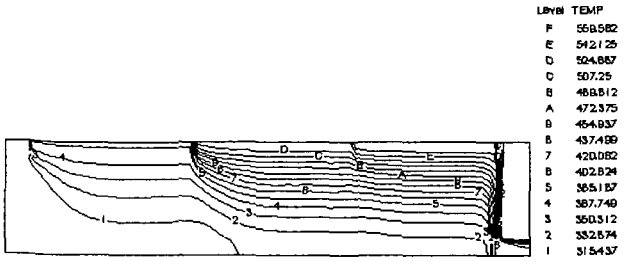


(b) Time = 15 min

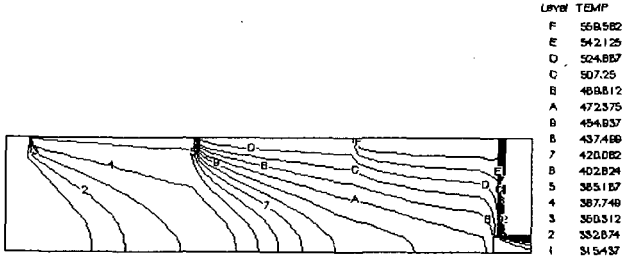


(c) Time = Steady

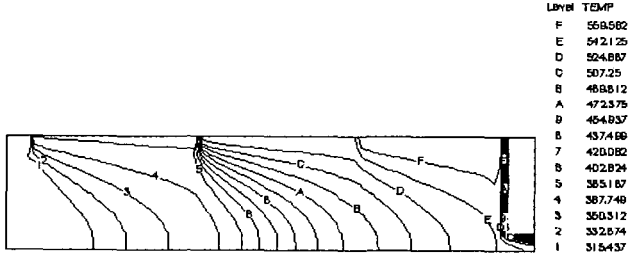
Figure 3. The maps of temperature for case1.



(a) Time = 5 min



(b) Time = 15 min



(c) Time = Steady

Figure 4. The maps of temperature for case8.

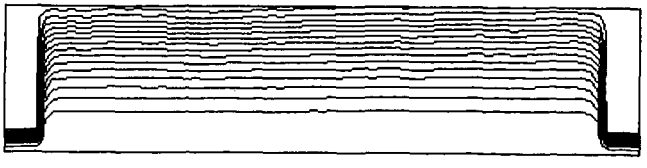


Figure 5. Streamlines in the reactor